Assessment of Odour Annoyance by the Use of Dispersion Models and Odour Impact Criteria: A Sensitivity Study

G. Schauberger[1], M. Piringer[2] and E. Petz[2]

[1]Institute of Medical Physics and Biostatistics, University of Veterinary Medicine Vienna, Austria
[2]Central Institute for Meteorology and Geodynamics, Department of Environmental Meteorology, Vienna, Austria

Abstract

The Austrian odour dispersion model (AODM) is a Gaussian model suitable for the prediction of ambient odour concentrations. Based on cumulative frequency distributions of calculated odour concentrations at receptor points, separation distances are obtained defined by odour impact criteria chosen as a combination of odour threshold and probability of threshold exceedance.

Here, the AODM is used to calculate separation distances for various odour impact criteria which are defined by an odour threshold and the exceedance probability for a site in the Austrian North-alpine foreland. For these direction-dependent separation distances we analysed the sensitivity of the separation distance for the two parameters of the odour impact criteria.

We selected typical odour impact criteria used in various countries around the world. The definitions of these national odour impact criteria differ to quite an extent.

By using the separation distance as a final proof value, we analysed the variation of the separation distance due to the change of the odour impact criteria. The results show a sensitivity depending on the direction. The sensitivity is less pronounces for the prevailing wind directions. The separation distances show less variation with the wind direction for a higher protection level. The lower the protection level the higher the influence of the prevailing wind direction.

Materials and Methods

Only a brief summary is given here; details are found e. g. in Schauberger et al. (2002).

Short Description of the AODM

The calculation of odour release is based on a steady-state balance of the sensible heat flux, used to calculate the indoor temperature, and the ventilation rate of the livestock unit (Schauberger et al., 2000b). The corresponding odour flow in OU/m³ is assessed by a simple model for odour release described by Schauberger et al. (1999 & 2000b). The chosen system parameters typical for a livestock building in middle Europe (Schauberger et al., 1993) can be found in detail in Schauberger et al. (2001 and 2002). The results were calculated for a mechanically ventilated pig fattening unit with 1000 pigs. The following parameters were calculated every half-hour over the two year period: outlet air temperature, outlet air velocity, volume flow of the ventilation system, odour concentration of the outlet air. The odour flow in OU/s is calculated by the product of the volume flow of the building in m³/s and odour concentration of the outlet air in OU/m³.

The mean ambient odour concentrations are calculated using the Austrian Gaussian regulatory dispersion model (ÖNorm M 9440, 1992/96), a Gaussian plume model for single stack emissions. The model has been validated internationally (e. g. Pechinger and Petz, 1999). The mean odour concentrations of the dispersion model are transformed to instantaneous values depending on wind velocity and atmospheric stability. The meteorological background to calculate the instantaneous values using a peak-to-mean parameterisation is described in detail by Schauberger et al. (2000a).

Calculating Sensation and Separation Distance

The separation distance is calculated for eight wind direction classes (sectors of 45°) in two steps: First, sensation distances, defined as distances from the source where the momentary odour concentration is equal to the selected odour threshold, are calculated for each half–hourly period of the meteorological 2-

year time series. The second step is the calculation of the separation distance. Therefore, selected limits of the combination of odour concentration threshold T and probability of the threshold exceedance p are taken.

By the combination of these two values the protection level is defined. In Tab. 1 various national odour impact criteria were summarised. Based on these two values, we investigated the sensitivity of the separation distance in relation to the odour impact criteria. The separation distance was calculated for following combinations: the odour threshold 1, 3, and 5 OU/m^3 and the exceedance probability 1, 3, 5, and 7%. The sensitivity of the separation distance S was analysed for a constant odour threshold T (Fig. 2 and Tab. 3) and for constant exceedance probability p (Fig. 3. and Tab. 4). For these two cases we used the slope of a regression line. The slope gives the change of the separation distance ΔS for the change of the odour threshold ΔT or the exceedance probability Δp (Tab. 3 and 4). The coefficient of variation of the separation distance was calculated for all 12 odour impact criteria to express the direction-depending variation (Tab. 5). The lower the coefficient of variation the higher the isotropy of the separation distances.

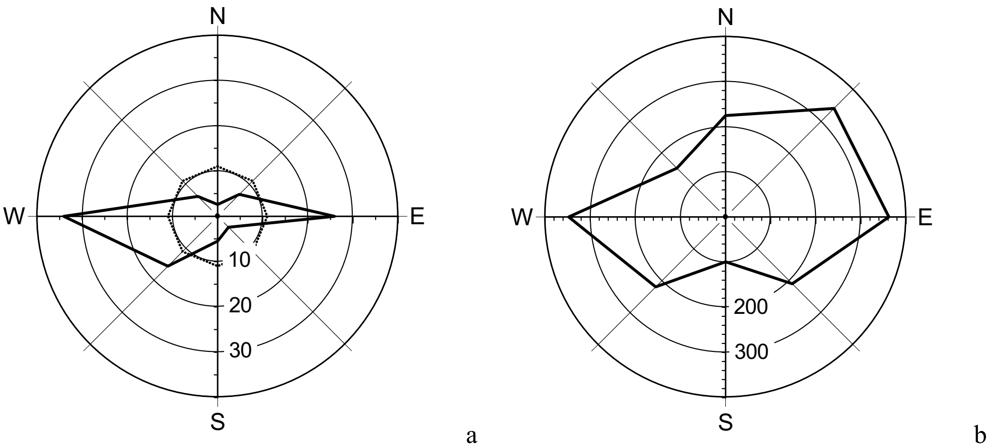


Figure 1. Polar diagram of (a) relative frequency distribution of the wind direction at Wels for eight 45° sectors. Calm conditions according to the ÖNorm M 9440 (1992/1996) with wind velocity less than 0.7 m/s evenly distributed over all directions (dotted line) and (b) separation distances (in m) calculated by the model for eight wind directions based on an odour concentration threshold of 1 OU/m^3 and the probability of the threshold exceedance of 3 %.

As an example we selected a threshold of 1 OU/m^3 and a probability of the threshold exceedance of 3% indicating that, during a typical year, there are 525 out of 17520 half hourly periods (3%) during which the ambient odour concentrations will be momentarily above 1 OU/m^3 (Fig. 1). On the basis of the cumulative probability of the sensation distances for each of the eight wind direction sectors, the separation distances are calculated for the selected odour impact criterion. For a selected wind direction sector, the distance at which this definition is fulfilled, is called separation distance. E.g. for North wind, the corresponding separation distance points to the South of the odour source (Schauberger et al., 2002).

Table 1. Odour impact criteria: Limits of odour concentration and exceeding probability used in Austria, Germany, UK, Australia, The Netherlands, Denmark, New Zealand and Massachusetts (USA) (Schauberger et al.,2001)

Odour impact criteria[1]	Land use category[2]	Comment
Germany		
1 OU/m³ / 10%	pure residential areas and residential areas	
1 OU/m³ / 15%	residential and structured areas	
UK		
10 OU/m³ / 2%		Serious annoyance expected with near certainty
5 OU/m³ / 2%		Generally acceptable for existing installations. Emissions from stacks or large area sources may be acceptable at the relaxed end of the range
1 OU/m³ / 2%		No serious annoyance expected in the large majority of cases
1 OU/m³ / 0.5%		Safe target value for new sources
10 OU/m³ / 0.01%		Safe target value for new sources applicable to highly intermittent sources
Austria		
1 OU/m³ / 8% and 3 OU/m³ / 3%		threshold for reasonable odour sensation for medical purpose
Australia		
5 OU/m³ / 0.5%	rural and urban area	
2 OU/m³ / 0.5%	residential area	New South Wales
10 OU/m³ / 0.5%	residential areas	Victoria
The Netherlands		
1 OU/m³ / 2%	residential areas	existing units
1 OU/m³ / 0.5%	residential areas	new installations
1 OU/m³ / 5%	residential areas outside of villages and business areas	
Denmark		
5 - 10 OU/m³ / 0.1%		plants
0.6 – 20 OU/m³ / 1%		surrounding
New Zealand		
2 OU/m³ / 0.5%		property boundary
Massachusetts, USA		
5 OU/m³ / 0.5%		plant boundary

[1] Odour concentration threshold (OU/m^3) / exceeding probability p (%)
[2] The lend use category varies the accepted protection level

Meteorological Conditions

The meteorological data for January 30, 1992 to January 31, 1994 were collected at Wels, a site representative of the Austrian flatlands north of the Alps. The sample interval was 30 minutes. The city of Wels in Upper Austria is a regional shopping and business centre with a population of about 50,000. The surrounding area is rather flat and consists mainly of farmland. The mean wind velocity 10 m above the mean roof top level of 15 m is 2.2 m/s with a maximum velocity of about 13 m/s. The distribution of wind directions is shown in Fig. 1a.

Discrete stability classes have been determined based on sun elevation angle, cloud cover and low cloud base height, and wind speed (Reuter, 1970). The cloud data are measured at the Linz-Hörsching airport, about 13 km from Wels. Within the Reuter scheme, classes 2 to 7 can occur in Austria. Stability classes 2 and 3, which by definition occur only during daylight hours in a well-mixed boundary layer, class 3 allowing also for cases of high wind velocity and moderate cloud cover, occur in 26% of all cases. Stability class 4, representing cloudy and/or windy conditions including precipitation or fog, occurs day and night (43 %). Class 5 occurs with higher wind velocity during nights with low cloud cover, a situation which is not observed frequently at Wels (6 %). Classes 6 and 7 are relevant for clear nights, when a surface inversion, caused by radiative cooling, traps pollutants near the ground. Such situations occur in 25% of all cases.

Northerly and southerly winds show a behaviour which suggests an influence of the North-South oriented Alm river valley running into the Alpine foreland south of Wels. Northerly up-valley winds are more frequent during daytime, southerly down-valley winds more frequent during night. Therefore northerly winds are frequently associated with stability classes 2 to 4, southerly winds with classes 4 to 7. For both wind directions, the average wind velocity is rather small, with the 75 %-percentile at 1.1 m/s for North and at 1.9 m/s for South wind, respectively. In accordance with these findings, odour sensation at the separation distance for northerly winds (all half-hours) shows a maximum during daytime (between 7:00 and 20:00) and occurs frequently more often during the spring and summer months. For southerly winds, the odour sensation at the separation distance has its maximum in the evening (after 18:00), is large throughout the night, and shows a local maximum in the morning (before 6:00). South wind is more frequent from late summer through autumn to January.

Table 2: Relative frequency of the eight classes of wind directions

Wind direction	Relative frequency (%)
N	2.6
NE	6.8
E	25.9
SE	3.4
S	5.5
SW	15.6
W	34.1
NW	6.2

East and West winds are the dominant directions at Wels. Both directions show no strong variation over the day and some but no systematic variability across the year. Both directions are associated with much stronger wind velocities than North and South wind: the most frequent velocities for East wind are around 3 m/s, for West wind around 4 m/s. Maximum velocities are around 9 m/s for East wind and around 13 m/s for West wind. The distribution of stability classes with East and West winds is relatively similar to the overall distribution, due to the large frequency of these directions. Stability class 4 dominates, especially for West wind frequently in conjunction with high wind velocities, cloudiness, and rain. Classes 2 and 3 as well as 6 and 7 are more common with East wind associated with anticyclonic conditions. For East and West winds, odour sensation at the separation distance takes place more often in the second half of the day, with peaks around 22 CET, and from October to January. For both directions, the dependence of odour sensation on wind velocity shows several peaks, mostly at 1 and from 3 to 5 m/s. For East wind, odour sensation occurs only with stability classes 4 to 7; for West wind, it occurs with classes 4 to 6; classes 2 and 3 are free from odour sensation for the selected odour impact criterion, which is an effect of the large separation distances for these directions.

Results

The sensitivity of the separation distance S was calculated analysed for a constant odour threshold T (Fig. 2 and Tab. 3) and for constant exceedance probability p (Fig. 3. and Tab. 4).

For a certain odour threshold (e.g. 1 OU/m³ in Fig 2a) the sensitivity shows a minimum for the prevailing wind directions East, South-West, and East. The sensitivity of these wind directions lies between 7 and 12 m/%. The other directions this gradient is about 3 to 4-fold higher. For the highest protection level (1 OU/m³ / 1%) the coefficient of variation was lowest with about 36%. This means that the separation distance S doesn't change a lot with the direction. With growing exceedance probability the direction-dependent variability of the separation distances increases.

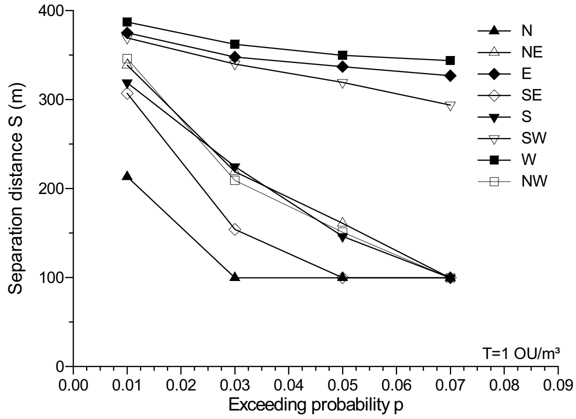
The influence of the exceedance probability is reduced for higher odour thresholds (Fig. 2b and 2c). For an odour threshold of 5 OU/m³ the sensitivity for the three prevailing wind directions is about 3 to 8m/% and about the 2-fold for the other wind directions which are more related to the valley wind system.

Table 3. Change of the separation distance ΔS (m) for increasing exceeding probability Δp (%).

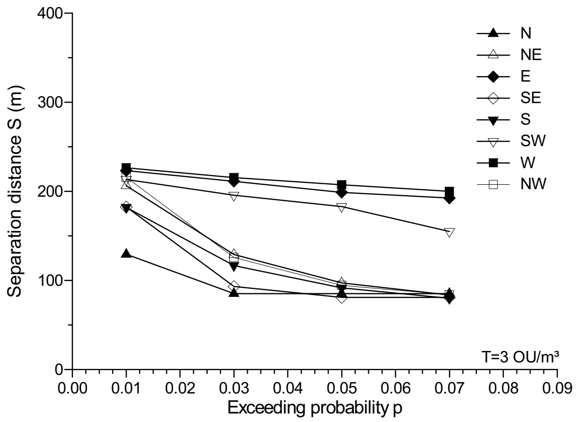
	ΔS / Δp (m / %)		
Winddirection	Odour threshold T (OU/m³)		
	1	3	5
N	-17	-7	-7
NE	-39	-20	-17
E	-8	-5	-5
SE	-34	-16	-15
S	-37	-17	-15
SW	-12	-9	-8
W	-7	-4	-3
NW	-40	-21	-19

Table 4. Change of the separation distance ΔS (m) for an increasing odour threshold ΔT (OU/m³).

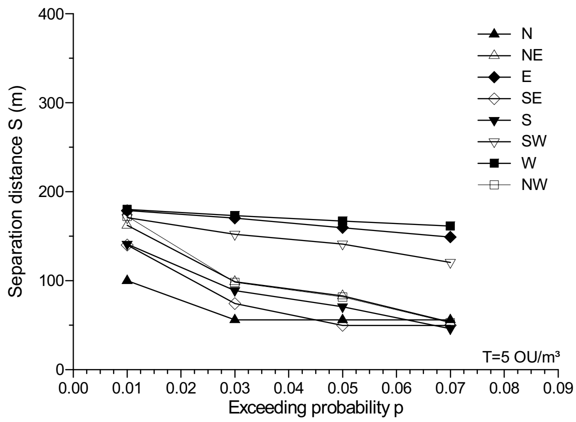
	ΔS / ΔT (m / OU/m³)			
Winddirection	Exceeding probability p (%)			
	1	3	5	7
N	-28	-11	-11	-11
NE	-44	-30	-20	-11
E	-49	-44	-44	-44
SE	-42	-20	-13	-13
S	-44	-34	-19	-13
SW	-50	-47	-45	-43
W	-52	-47	-46	-46
NW	-43	-28	-17	-12



a



b



c

Figure 2. Sensitivity of the separation distance S (m) as a function of the exceeding probability p for various odour thresholds T of 1 OU/m² (a), 3 OU/m² (b), and 5 OU/m² (c).

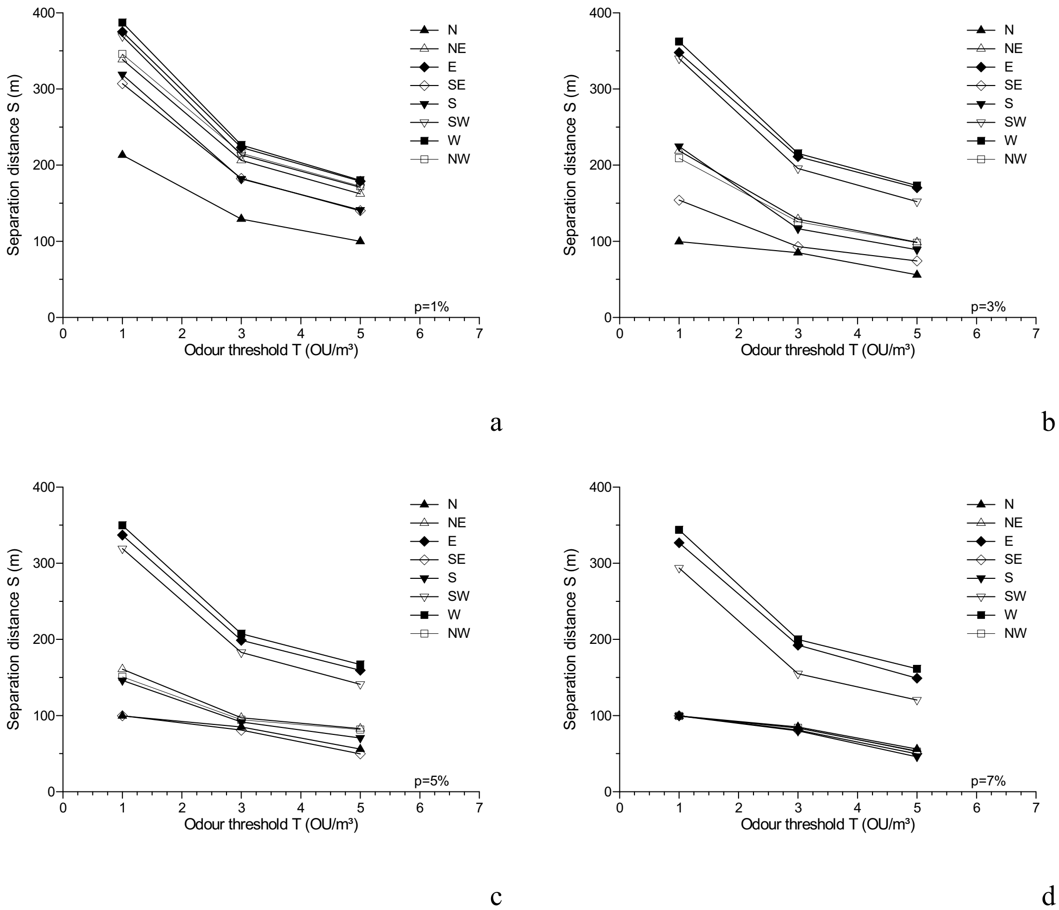


Figure 3. Sensitivity of the separation distance S (m) as a function of the odour threshold T for various exceeding probabilities p of 1 % (a), 3 % (b), 5 % (b), and 7 % (d).

For an exceedance probability of 1 % (Fig 3a) the sensitivity is nearly the same for all wind directions. For an increasing exceedance probability a separation for the prevailing wind directions (E, SW, W) and the other wind directions could be found. For an exceedance probability of 7% the sensitivity is about 45 m / OU/m³ compared to 10 to 13 m / OU/m³ for those wind directions which are dominated by the local wind system.

Table 5. Coefficient of variation of the separation distance S (OU/m³) for the selected odour impact criteria as a measure for the isotropy

	Coefficient of variation (%)			
Odour threshold T (OU/m³)	Exceeding probability p (%)			
	1	3	5	7
1	0.368	0.497	0.590	0.680
3	0.367	0.475	0.522	0.532
5	0.372	0.498	0.550	0.629

Discussion

From Table 1 it is apparent that odour thresholds in combination with their exceeding probabilities are explicitly related to land-use categories in Germany, the Netherlands, and Australia only. In all these countries, residential areas, in which, apart from existing installations, animal farming usually is not allowed, are best protected. However, the threshold systems are different. In Germany and the Netherlands, only the exceeding probability varies according to the land-use category. In Australia, the odour threshold varies, whereas the exceeding probability is fixed. In the UK, the odour thresholds are related to different levels of annoyance. Depending on the kind of odour threshold fulfilled for the investigated farm, the level of annoyance can be determined. Property domains are relevant for the validity of odour thresholds in Denmark, New Zealand, and Massachusetts, USA. Medical aspects led to the definition of the Austrian odour threshold.

The definitions of the various national odour impact criteria differ to quite an extent. Miedema and Ham (1988) and Miedema et al. (2000) found a strong relationship between the 98 percentile of the odour concentration and the percentage of the highly annoyed neighbours. They used an ambient odour concentration for an integration time of 1 hour, calculated by a dispersion model without consideration of the peak-to mean ratio. In Germany, the odour impact criterion is defined by an exceedance probability of 10% for a threshold of 1 OU/m^3. To apply this odour impact criterion, the calculated odour concentration (one hour mean value of the regulatory dispersion model) is multiplied by a constant factor of 10 by using the Gaussian dispersion model or the factor 4 for the recently publishes Lagrange models (AUSTAL 2000G).

Apart from the exceedance probability, the odour concentration threshold of the impact criterion is of importance. The odour is measured by the human nose as a sensor by comparing a diluted odour sample with odour free air. This means that the detection threshold of 1 OU/m^3 can only be perceived in an odour free environment (laboratory). Therefore the perceived odour concentration in the field must be higher than 1 OU/m^3 to be distinguished against the background concentration. Field experiments must be designed such that an odour source can be distinguished against the background odour. Nicell (1994) assumes an odour concentration of 3 OU/m^3 to allow for a discrimination, and one of 5 OU/m3 for unmistakable perception (also defined as a complaint level).

Further on, the perception of the odour intensity goes with the logarithm of the odour concentration according to the Weber-Fechner law (e. g., Misselbrook et al., 1993). Based upon laboratory-based experiments on perceived intensity, the Environment Agency, UK (2002), defines: 1 OU/m^3 is the point of detection, 5 OU/m^3 is a faint odour, and 10 OU/m^3 is a distinct odour. The discrepancy between the definition of 1 OU/m^3 in the laboratory by using odour free air and the situation in the field was solved by introducing the sniffing unit (van Langenhove and van Broeck, 2001; Defoer and van Langenhove, 2003).

All these aspects of the odour impact criteria show the difficulties to compare various methods used in different countries.

Conclusions

The odour impact criteria were selected predominantly by the administration and the legislation. The argumentation for the selection of the two values of the odour threshold and the exceedance probability seems not very sound.

By the fact that the odour impact criteria are the interface between the dispersion model and the annoyance potential a critical evaluation of the selected values should be done.

References

Defoer, N.; van Langenhove, H.; 2003. Determination of odour emissions from pig farms for regulatory purposes in Flanders. in International Symposium on Gaseous and Odour Emissions from Animal Production Facilities. 152-160, Horsens, Denmark.

Environment Agency, 2002. Integrated Pollution Prevention and Control (IPPC). Horizontal Guidance for Odour Part 1 – Regulation and Permitting (draft). Scientific and Technical Information Service, Bristol, UK.

Miedema, H. M. E.; Ham, J. M.; 1988. Odour annoyance in residential areas. *Atmospheric Environment*, 22 (11), 2501-2507

Miedema, H. M. E.; Walpot, J.I.; Vos, H.; Steunberg, C.F.; 2000. Exposure-annoyance relationship for odour from industrial sources. *Atmospheric Environment*, 43, 2927-2936.

Misselbrook, T.H.; Clarkson, Pain, C.R.; B.F.; 1993. Relationship between concentration and intensity of odour for pig slurry and broiler houses. *J of Agricultural Engineering Research*, 55, 163-169

Nicell, J.A.; 1994. Development of the odour impact model as a regulatory strategy. Int. J. *Environment and Pollution*, 4, 124-138.

ÖNorm M 9440, 1992/1996. Ausbreitung von luftverunreinigenden Stoffen in der Atmosphäre; Berechnung von Immissionskonzentrationen und Ermittlung von Schornsteinhöhen [Dispersion of pollutants in the atmosphere – calculation of the ambient air concentrations and determination of stack heights]. Österreichisches Normungsinstitut, Vienna.

Pechinger, U., Petz, E., 1999. Model evaluation of the Austrian Gaussian plume model ON M 9440: comparison with the Kincaid data set. *Int. J. Environ. Pollut*. 5, 338 – 349.

Reuter, H.; 1970. Die Ausbreitungsbedingungen von Luftverunreinigungen in Abhängigkeit von meteorologischen Parametern [Dispersion conditions of airborne pollutants in dependence on meteorological parameters]. *Archiv für Meteorologie und Geophysik, Bioklimatologie* A, 19, 173-186

Schauberger, G., Wudy, W., Cernohorsky, W., 1993. Statistisch-repräsentative Erhebung der Stallklimasituation in Rinder- und Schweineställen in Niederösterreich - Tierbestand, Gebäude und Lüftung. *Wiener Tierärztliche Monatsschrift*. German. 80, 364-374.

Schauberger, G.; Piringer, M.; Petz, E.; 1999. Diurnal and annual variation of odour emission of animal houses: a model calculation for fattening pigs. *Journal of Agricultural Engineering Research*, 74 (3) 251-259

Schauberger, G.; Piringer, M.; Petz, E.; 2000a. Diurnal and annual variation of the sensation distance of odour emitted by livestock buildings calculated by the Austrian odour dispersion model (AODM) *Atmospheric Environment*, 34 (28) 4839-4851

Schauberger, G.; Piringer, M.; Petz, E.; 2000b. Steady-state balance model to calculate the indoor climate of livestock buildings demonstrated for fattening pigs. *International Journal of Biometeorology*, 43 (4) 154-162

Schauberger, G.; Piringer, M.; Petz, E.; 2001. Separation distance to avoid odour nuisance due to livestock calculated by the Austrian odour dispersion model (AODM). *Agriculture, Ecosystems & Environment*, 87 (1) 13-28

Schauberger, G.; Piringer, M.; Petz, E.; 2002. Calculating direction-dependent separation distance by a dispersion model to avoid livestock odour annoyance. *Biosystems Engineering*, 82 (1) 1-24

van Langenhove, H.; van Broeck, G.; 2001. Applicability of sniffing team observations: experience of field measurements *Water Science & Technology*, 44, 65–70